Internet Protocol
Version 6 (IPv6)

Raj Jain
Washington University
Saint Louis, MO 63131
Jain@cse.wustl.edu

These slides are available on-line at:
http://www.cse.wustl.edu/~jain/cse473-05/
Overview

Limitations of IPv4 Addressing
IPv6 Enhancements
IPv6 Addresses
IP v6 Header
IPv6 Extension Headers
IP Addresses

Example: 164.107.134.5
= 1010 0100 : 0110 1011 : 1000 0110 : 0000 0101
= A4:6B:86:05 (32 bits)

Maximum number of address = $2^{32} = 4$ Billion

Class A Networks: 15 Million nodes
Class B Networks: 64,000 nodes or less
Class C Networks: 254 nodes or less
IP Address Format

Three all-zero network numbers are reserved
127 Class A + 16,381 Class B + 2,097,151 Class C networks = 2,113,659 networks total
Class B is most popular.
20% of Class B were assigned by 7/90 and
doubling every 14 months ⇒ Will exhaust by 3/94
Question: Estimate how big will you become?
Answer: More than 256!
Class C is too small. Class B is just right.
How Many Addresses?

10 Billion people by 2020
Each person will be served by more than one computer
Assuming 100 computers per person ⇒ $10^{12}$ computers
More addresses may be required since
- Multiple interfaces per node
- Multiple addresses per interface
Some believe $2^6$ to $2^8$ addresses per host
Safety margin ⇒ $10^{15}$ addresses
IPv6 Requirements ⇒ $10^{12}$ end systems and $10^9$ networks. Desirable $10^{12}$ to $10^{15}$ networks
IPv6 Enhancements

1. Expanded address space: 128 bit
2. Address auto-configuration: Dynamic assignment
3. Increased addressing flexibility: Anycast + Multicast
4. Improved option mechanism: Extension Headers
   Improved speed and simplified router processing
5. Support for resource allocation
   Replaces type of service
   Labeling of packets to particular traffic flow
IPv6 Addresses

128-bit long. Fixed size

\[ 2^{128} = 3.4 \times 10^{38} \text{ addresses} \]

\[ \Rightarrow 665 \times 10^{21} \text{ addresses per sq. m of earth surface} \]

If assigned at the rate of \( 10^6/\mu\text{s} \), it would take 20 years

Expected to support \( 8 \times 10^{17} \) to \( 2 \times 10^{33} \) addresses

\( 8 \times 10^{17} \Rightarrow 1,564 \text{ address per sq. m} \)

Allows multiple interfaces per host.

Allows multiple addresses per interface

Allows unicast, multicast, anycast

Allows provider based, site-local, link-local
Colon-Hex Notation

Dot-Decimal: 127.23.45.88

Colon-Hex:
FEDC:0000:0000:0000:3243:0000:0000:ABCD

Can skip leading zeros of each word
Can skip one sequence of zero words, e.g.,
FEDC::3243:0000:0000:ABCD
::3243:0000:0000:ABCD

Can leave the last 32 bits in dot-decimal, e.g.,
::127.23.45.88

Can specify a prefix by /length, e.g.,
2345:BA23:0007::/50
Local-Use Addresses

- **Link Local**: Not forwarded outside the link, FE:80::xxx
  - 10 bits | n bits | 118-n
  - 1111 1110 10 | 0 | Interface ID

- **Site Local**: Not forwarded outside the site, FE:C0::xxx
  - 10 bits | n bits | m bits | 118-n-m bits
  - 1111 1110 11 | 0 | Subnet ID | Interface ID

- Provides plug and play
Multicast Addresses

<table>
<thead>
<tr>
<th>8 bits</th>
<th>4 bits</th>
<th>4 bits</th>
<th>112 bits</th>
</tr>
</thead>
<tbody>
<tr>
<td>1111 1111</td>
<td>Flags</td>
<td>Scope</td>
<td>Group ID</td>
</tr>
<tr>
<td>0000</td>
<td>T</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$T = 0 \Rightarrow$ Permanent (well-known) multicast address,
$1 \Rightarrow$ Transient

Scope: 1 Node-local, 2 Link-local, 5 Site-local,
8 Organization-local, E Global

Predefined: 1 $\Rightarrow$ All nodes, 2 $\Rightarrow$ Routers,
1:0 $\Rightarrow$ DHCP servers
Multicast Addresses (Cont)

Example: 43 ⇒ Network Time Protocol Servers
   FF01::43 ⇒ All NTP servers on this node
   FF02::43 ⇒ All NTP servers on this link
   FF05::43 ⇒ All NTP servers in this site
   FF08::43 ⇒ All NTP servers in this organization
   FF0E::43 ⇒ All NTP servers in the Internet
## Header

### IPv6:

<table>
<thead>
<tr>
<th>Ver</th>
<th>Traffic Class</th>
<th>Flow Label</th>
<th>Payload Length</th>
<th>Next Header</th>
<th>Hop Limit</th>
<th>Source Address</th>
<th>Destination Address</th>
</tr>
</thead>
</table>

### IPv4:

<table>
<thead>
<tr>
<th>Version</th>
<th>IHL</th>
<th>Type of Service</th>
<th>Total Length</th>
<th>Identification</th>
<th>Flags</th>
<th>Fragment Offset</th>
<th>Time to Live</th>
<th>Protocol</th>
<th>Header Checksum</th>
<th>Source Address</th>
<th>Destination Address</th>
<th>Options</th>
<th>Padding</th>
</tr>
</thead>
</table>
IP v6 Header

Version: 6
Traffic Class: Classes or priorities of packet
Flow Label: Used by hosts requesting special handling
Payload length: Includes all extension headers + data
Next Header: Extension header or next layer up
Source Address
Destination address
## Protocol and Header Types

<table>
<thead>
<tr>
<th>Decimal</th>
<th>Keyword</th>
<th>Header Type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HBH</td>
<td>Hop-by-hop (IPv6)</td>
</tr>
<tr>
<td>1</td>
<td>ICMP</td>
<td>Internet Control Message (IPv4)</td>
</tr>
<tr>
<td>2</td>
<td>IGMP</td>
<td>Internet Group Management (IPv4)</td>
</tr>
<tr>
<td>2</td>
<td>ICMP</td>
<td>Internet Control Message (IPv6)</td>
</tr>
<tr>
<td>3</td>
<td>GGP</td>
<td>Gateway-to-Gateway</td>
</tr>
<tr>
<td>4</td>
<td>IP</td>
<td>IP in IP (IPv4 Encapsulation)</td>
</tr>
<tr>
<td>5</td>
<td>ST</td>
<td>Stream</td>
</tr>
<tr>
<td>6</td>
<td>TCP</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>UDP</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>ISO-TP4</td>
<td></td>
</tr>
<tr>
<td>43</td>
<td>RH</td>
<td>Routing Header (IPv6)</td>
</tr>
<tr>
<td>44</td>
<td>FS</td>
<td>Fragmentation Header (IPv6)</td>
</tr>
<tr>
<td>45</td>
<td>IDRP</td>
<td>Interdomain Routing</td>
</tr>
<tr>
<td>51</td>
<td>AH</td>
<td>Authentication header (IPv6)</td>
</tr>
<tr>
<td>52</td>
<td>ESP</td>
<td>Encrypted Security Payload</td>
</tr>
<tr>
<td>59</td>
<td>Null</td>
<td>No next header</td>
</tr>
<tr>
<td>60</td>
<td>ISO-IP</td>
<td>CLNP</td>
</tr>
<tr>
<td>88</td>
<td>IGRP</td>
<td></td>
</tr>
<tr>
<td>89</td>
<td>OSPF</td>
<td>Open Shortest Path First</td>
</tr>
</tbody>
</table>
IPv6 vs IPv4

1995 vs 1975
IPv6 only twice the size of IPv4 header
Only version number has the same position and meaning as in IPv4
Removed: header length, type of service, identification, flags, fragment offset, header checksum
Datagram length replaced by payload length
Protocol type replaced by next header
Time to live replaced by hop limit
Added: Priority and flow label
All fixed size fields.
IPv6 vs IPv4 (Cont)

No optional fields. Replaced by extension headers.
8-bit hop limit = 255 hops max (Limits looping)
Next Header = 6 (TCP), 17 (UDP),
**Extension Headers**

<table>
<thead>
<tr>
<th>Base Header</th>
<th>Extension Header 1</th>
<th>Extension Header n</th>
<th>Data</th>
</tr>
</thead>
</table>

Most extension headers are examined only at destination:

1. Hop-by-Hop Options
2. Fragmentation: All IPv6 routers can carry 536 Byte payload
3. Routing: Loose or tight source routing
4. Destination Options
### Extension Header (Cont)

**Only Base Header:**

<table>
<thead>
<tr>
<th>Base Header</th>
<th>TCP Segment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Next = TCP</td>
<td></td>
</tr>
</tbody>
</table>

**Only Base Header and One Extension Header:**

<table>
<thead>
<tr>
<th>Base Header</th>
<th>Route Header</th>
<th>TCP Segment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Next = Routing</td>
<td>Next = TCP</td>
<td></td>
</tr>
</tbody>
</table>

**Only Base Header and Two Extension Headers:**

<table>
<thead>
<tr>
<th>Base Header</th>
<th>Hop Header</th>
<th>Routing Header</th>
<th>TCP Segment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Next = Hop</td>
<td>Next = Routing</td>
<td>Next = TCP</td>
<td></td>
</tr>
</tbody>
</table>
Hop-by-hop Options Header

<table>
<thead>
<tr>
<th>8b</th>
<th>8b</th>
<th>16b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Next Hdr</td>
<td>Hdr Ext Len</td>
<td>One or more options</td>
</tr>
</tbody>
</table>

- Jumbo payload: Over $2^{16} = 65,535$ octets
- Router alert
  - Contents of packet is of interest to router
  - Provides support for RSVP
### Fragmentation Header

<table>
<thead>
<tr>
<th>8b</th>
<th>8b</th>
<th>13b</th>
<th>2b</th>
<th>1b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Next Hdr</td>
<td>Reserved</td>
<td>Fragment Offset</td>
<td>Res</td>
<td>More</td>
</tr>
<tr>
<td>Identification</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Fragmentation only allowed at source
- No fragmentation at intermediate routers
- Node must perform path discovery to find smallest MTU of intermediate networks
- Source fragments to match MTU
- Otherwise limit to 1280 octets
# Routing Header

<table>
<thead>
<tr>
<th>Next Header</th>
<th>Hdr Ext Len</th>
<th>Routing Type</th>
<th>Segments Left</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Reserved</td>
</tr>
<tr>
<td></td>
<td>Address 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Address 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Address n</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Strict** $\Rightarrow$ Discard if Address[Next-Address] $\neq$ neighbor
- **Type = 0** $\Rightarrow$ Loose source routing
- **IPv6 Destination Address = Next Address**
- **Segments Left**: Number of route segments remaining
- **IPv6 Dest Adr and Segments left** are updated as each address specified in the list is reached
Destination Options

Same format as Hop-by-Hop options header
Summary

1. IPv6 uses 128-bit addresses
2. Allows site-local, link-local, multicast, anycast addresses
3. Fixed header size. Extension headers instead of options
4. Hop-by-hop options, fragmentation, routing, destination options headers
Reading Assignment

Read Section 18.5 of Stallings’s 7th edition